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International Trade and Environmental Policy Under Imperfect Competition

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ABSTRACT

The objective of the present paper is to review the literature on the link between environmental policy and international trade, with a focus on imperfect competition on the world output markets. Special attention will be paid to the literature on oligopoly and strategic government policy and its potential consequences for the ecological dumping debate. We address partial equilibrium as well as general equilibrium approaches, and emphasize the fact that opposing conclusions can be reached.

Keywords: Ecological dumping; imperfect competition; international trade; pollution.

1 INTRODUCTION

The pollution haven hypothesis is defined by Taylor (2004, p. 1) as a prediction that "liberalized trade in goods will lead to the relocation of pollution intensive production from high income and stringent environmental regulation countries, to low income and lax environmental regulation countries." The pollution haven hypothesis was first envisaged by Copeland and Taylor (1994). This seminal piece of work was followed by a large number of other important contributions by the same authors and culminated in

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their recent book (Copeland and Taylor 2003). A recent issue of *Advances in Economic Analysis and Policy* and *Contribution to Economic Analysis and Policy* (2004) was entirely devoted to the pollution haven hypothesis (see Fullerton 2006), including an excellent survey by Taylor (2004). Therefore, there appears to be not much room for another survey on the topic. However, most of the literature on the pollution haven hypothesis is aiming at empirical applications[1] and relatively minor attention is paid to the economic theory behind the hypothesis. Moreover, most of the existing theory focuses on conditions of perfect competition. It seems therefore worthwhile to pay attention to imperfect competition, thereby relating the pollution haven hypothesis to the existing theory of strategic trade policy and the environment. The latter topic was addressed earlier by Ulph (1997), but the present article aims to incorporate some more recent developments.

In the Copeland–Taylor approach a distinction can be made between exogenous and endogenous environmental policy. In the former case environmental policy is implemented independently of preferences or endowments, whereas in the latter environmental policy is aiming at maximizing social welfare. In our treatment of international trade and environmental policy, we will always concentrate on the latter type of policies. We will treat the Copeland–Taylor model in Section 2 of this article. We aim at a formal treatment, as in the rest of this article, because such an approach allows for a precise statement of the results and illustrates the exact role of the assumptions made.

Starting in Section 3, we review the existing literature on trade and the environmental in a non-competitive setting. This review is brief because it partly overlaps with Ulph's (1997) earlier excellent contribution. In Section 3, we also present a rather general model, in a partial as well as in a general equilibrium setting, that serves as the vehicle for in the remainder of the paper. We also explore the case of perfect competition and the large country case. Section 4 goes into oligopoly, and in particular treats the issue of strategic environmental policy. Thereby a distinction is made between Cournot and Bertrand competition. In this section, the partial equilibrium outcomes are derived and are related to the existing literature that already incorporates most of them. Section 5 discusses oligopoly and strategic environmental policy in general equilibrium models. It shows that the outcomes of the partial equilibrium models regarding optimal environmental policy may be reversed. Finally, Section 6, concludes.

Unfortunately, space restricts the topics that can be addressed. Hence, we do not go into the important issue of technology transfers that might counterbalance the pollution haven effect. As Di Maria and Smulders (2004) observe, if richer countries specialize in the production of clean commodities they might also direct R&D efforts to cleaner technology that might diffuse to other countries. Also Golombek and Hoel (2004) address technology transfer. Another important aspect of international trade and the environment is the property rights differential that might exist between developed and less developed countries and that might lead to overexploitation of natural resources and consequently welfare losses. The seminal papers here are by Chichilnisky (1993 and 1994). More recent contributions are by Brander and Taylor (1997) and Karp *et al.* (2001). Finally, we will not go into location choices as a consequence of environmental

[1] A list of references to the empirical literature is given at the end of the paper.

policy. It will be assumed throughout that all policy effects are materialized only in trade patterns and not in a change of location of plants or of persons. For the literature on location aspect of firms see e.g., Markusen *et al.* (1993 and 1995), Motta and Thisse (1994) and Hoel (1997). Elbers and Withagen (2004), Haavio (2003a and 2003b) and Hoel and Shapiro (2003) study location choices of workers.

Finally, before embarking on the survey, a note on notation. Although we will review numerous contributions we aim at providing a uniform presentation in terms of notation. The symbols W, U, D, F, c, p, z, τ will denote social welfare, utility from consumption, environmental damage, production function, consumption, price, pollution and emission taxes, respectively. Subscripts refer to different commodities and superscripts to firms. The distinction between home and foreign is usually indicated by superscript h and f.

2 THE COPELAND-TAYLOR MODEL

An extremely influential model is the Copeland–Taylor model, described in a number of publications by these authors and recently comprehensively treated in their 2003 book, from which we borrow extensively in this section. Our aim is to sketch how trade patterns depend on environmental policy in a competitive world.

By way of introduction for the reader unfamiliar with the trade environmental policy link, we first summarize what can be called the textbook approach, followed e.g., in Perman *et al.* (2003) or Pearson (2000). The simplest setting is a two country–two goods world in a partial equilibrium framework. The usual strategy is to derive the autarky equilibrium allocation and prices and to show that, in the absence of environmental externalities, opening up to free trade at given world market prices is beneficial from a welfare perspective. However, if production brings along local pollution and environmental policy is absent, the country exporting the dirty commodity may suffer a welfare loss because of the increased negative externality from pollution following increased production. But then it is shown that an optimal Pigouvian tax on pollution will restore the result that free trade increases welfare in both countries engaged in trade. The case of transboundary pollution is somewhat more complicated to analyze, because that would require coordinated policy. In the sequel we shall not address this issue.

Copeland and Taylor (2003) construct a general equilibrium two country (North and South), two goods, two factors model, in order to identify which of the two countries is going to be the exporter of the dirty commodity. Two hypotheses are investigated: the pollution haven hypothesis and the factor endowment hypothesis, both defined in the Introduction of this article.

The factors of production are labeled capital and labor; they are immobile across the two countries but mobile between sectors. Their initial endowments are k and l, respectively. The production function of the first commodity is $y_1 = z^{\alpha}[F_1(k_1, l_1)]^{1-\alpha}$ with $0 < \alpha < 1$ and F_1 linearly homogeneous in capital and labor input. Emissions z can be interpreted as arising from the use of a production factor such as energy. An alternative interpretation includes abatement. Without abatement emissions would be proportional to output, with factor of proportionality equal to unity. Abatement requires labor and capital, in the same proportion as in the "normal" production process. This is modeled as $y_1 = (1-\vartheta)F_1(k_1, l_1)$, $z = (1-\vartheta)^{1/\alpha}F_1(k_1, l_1)$, where ϑ is the abatement level, varying between 0 and 1. Output is used for consumption (c_1) and net exports (x_1). The second commodity is clean. Domestic consumption is c_2 and net exports are x_2. The given world market price is p. Production of the dirty commodity is always more capital intensive than the clean commodity: $(k_1/l_1) > (k_2/l_2)$. The instantaneous utility function U depends on consumption and is homothetic. Damage D is increasing and convex in emissions. The aim of the government is to maximize social welfare

$$W(c_1, c_2, z) = U(c_1, c_2) - D(z),$$

subject to

$$c_1 + x_1 = z^\alpha [F_1(k_1, l_1)]^{1-\alpha}, \tag{1}$$

$$c_2 + x_2 = F_2(k_2, l_2), \tag{2}$$

$$px_1 + x_2 = 0, \tag{3}$$

$$k = k_1 + k_2, \tag{4}$$

$$l = l_1 + l_2. \tag{5}$$

Equation (3) defines the equilibrium on the current account of the balance of trade, with the second commodity as the numeraire. The Lagrangian reads

$$\begin{aligned} L = \; & U(c_1, c_2) - D(z) + \mu_1[z^\alpha [F_1(k_1, l_1)]^{1-\alpha} - c_1 - x_1] + \mu_2[F_2(k_2, l_2) - c_2 - x_2] \\ & + \nu[px_1 + x_2] + \bar{r}[k - k_1 - k_2] + \bar{w}[l - l_1 - l_2]. \end{aligned}$$

Necessary conditions for an interior solution are:

$$\frac{\partial U}{\partial c_1} = \mu_1, \quad \frac{\partial U}{\partial c_2} = \mu_2, \tag{6}$$

$$D'(z) = \mu_1 \alpha z^{\alpha-1}[F_1(k_1, l_1)]^{1-\alpha}, \tag{7}$$

$$\mu_1(1-\alpha)z^\alpha F_1^{-\alpha}\frac{\partial F_1}{\partial k_1} = \bar{r}, \quad \mu_1(1-\alpha)z^\alpha F_1^{-\alpha}\frac{\partial F_1}{\partial l_1} = \bar{w}, \tag{8}$$

$$\mu_2\frac{\partial F_2}{\partial k_2} = \bar{r}, \quad \mu_2\frac{\partial F_2}{\partial l_2} = \bar{w}, \tag{9}$$

$$\mu_1 = \nu p, \quad \mu_2 = \nu. \tag{10}$$

Denote the optimal value of the variables and the corresponding Lagrangian multipliers by hats. Define

$$r = \frac{\hat{\bar{r}}}{\hat{\mu}_2}, \quad w = \frac{\hat{\bar{w}}}{\hat{\mu}_2}, \quad \tau = \frac{D'(\hat{z})}{\hat{\mu}_2}.$$

Then,

(i) $(\hat{c}_1, \hat{c}_2)$ maximizes $U(c_1, c_2)$ subject to

$$pc_1 + c_2 \leq rk + wl + \tau\hat{z} = rk + wl + [\,p\hat{z}^{\alpha}[F_1(\hat{k}_1, \hat{l}_1)]^{1-\alpha} - r\hat{k}_1 - w\hat{l}_1 - \tau\hat{z}]$$
$$+ [F_2(\hat{k}_2, \hat{l}_2) - r\hat{k}_2 - w\hat{l}_2] + \tau\hat{z} = p\hat{z}^{\alpha}[F_1(\hat{k}_1, \hat{l}_1)]^{1-\alpha} + F_2(\hat{k}_2, \hat{l}_2).$$

(ii) $(\hat{z}, \hat{k}_1, \hat{l}_1)$ maximizes $pz^{\alpha}[F_1(k_1, l_1)]^{1-\alpha} - rk_1 - wl_1 - \tau z$.
(iii) $(\hat{k}_2, \hat{l}_2)$ maximizes $F_2(k_2, l_2) - rk_2 - wl_2$.

So, consumers maximize utility subject to their budget constraint, producers maximize profits, given the rate of return r, the wage rate w and the tax on emissions τ, which is set equal to marginal damage, in money terms. Therefore, $(\hat{c}_1, \hat{c}_2, \hat{k}_1, \hat{k}_2, \hat{l}_1, \hat{l}_2, \hat{z}, q, r, w)$ constitutes a general competitive equilibrium. Hence by an appropriate choice of the pollution tax the first-best optimum can be implemented as a general equilibrium. It is important to realize that this is due to the fact that the world is perfectly competitive.

Due to the fact that the utility function U is homothetic, relative demand $RD(p) = c_1/c_2$ is a function of p only. It is decreasing. For a given z, national income $pz^{\alpha}[F_1(k_1, l_1)]^{1-\alpha} + F_2(k_2, l_2)$ is maximized in a general equilibrium, subject to (4) and (5). Hence, we can write $y_1 = y_1(k, l, e, z)$ and $y_2 = y_2(k, l, e, z)$, where $e = x/y_1$ is the pollution intensity in the polluting sector. Due to constant returns to scale these functions are linearly homogeneous in (k, l). Therefore, relative supply is $RS(p, e, k/l) = y_1(p, e, k/l)/y_2(p, e, k/l)$. It can be shown that under the assumptions made, relative supply is increasing in the price as well as in the capital labor ratio (the latter because the dirty sector is more capital intensive).

Now, consider first the case where North is relatively rich, but with the same relative factor endowment as South. If environmental policies would be such that the pollution intensities are identical, the equilibrium autarky price p would be identical, and there would be no reason for trade. However, with higher national income, social welfare maximization requires a more stringent environmental policy. Therefore the pollution intensity will be lower in the North than in the South, implying that the autarky price in North will be higher. This implies that when the countries open up to trade, North is going to import the dirty commodity and South is going to produce more of the dirty commodity, thereby causing more pollution as well. This is the pollution haven hypothesis. However, if environmental policy is set optimally in both countries, both countries will benefit from trade. Whether world pollution increases or decreases depends on the so-called income elasticity of marginal damage. As a consequence of trade income increases, which may call for a strong or a weak policy response, represented by the elasticity. If the required policy response is weak, total pollution may increase, otherwise it will increase.

A second experiment is to change the relative endowments. If the North is relatively capital abundant, then with identical emission intensities the North, whose production of the polluting commodity is relatively capital intensive, will export the dirty commodity.

These considerations clearly demonstrate the issues at stake. Differences in the relative abundance of capital enhance the factor endowment hypothesis: North will specialize in the production of the dirty commodity. Being rich, while relative endowments are identical, supports the pollution haven hypothesis through the policy effect.

3 IMPERFECT COMPETITION; AN INTRODUCTION

3.1 Introduction

Ideally, the Copeland–Taylor model of the previous section is extended so as to incorporate imperfect competition in a full-fledged general equilibrium model, to investigate the impact of strategic behavior of governments. However, to the best of our knowledge no literature on this topic has developed yet. Therefore, our objectives in the sequel of this survey are relatively modest. The aim of the present section is threefold. We first introduce a model that is employed in the sequel of this article. It is designed to address the main question posed in this literature, namely whether strategic considerations may lead governments to treat different sectors in the economy differently. In particular, a distinction will be made between the sheltered and the exposed sectors of the economy. The exposed sectors export their commodities, whereas the sheltered sectors do not. This allows us to analyze the question whether from a social welfare point of view it could be optimal to protect the exposed sectors, in the sense of making them subject to less stringent environmental policy. The second objective is to characterize the social optimum for the case of perfect competition and the "large country" case. Third, we deal with the implementation of the first-best in a decentralized economy.

3.2 The Model

The main ingredients of the model we employ are borrowed from the model constructed by Rauscher (1994) in his article on general equilibrium and environmental policy. We do not take into account abatement because for most of the results this is not essential. There are five commodities: three *consumer commodities*, *capital* and a *raw material*.

The first consumer commodity is produced and consumed domestically only. Production takes place in the so-called sheltered sector. This sector is composed of many firms that behave competitively. Aggregate technology is described by a production function (F_1), having capital (k_1) and the raw material (z_1) as inputs. Consumption is denoted by c_1. The second class of consumer commodities is produced domestically in $n(\geq 1)$ sectors, indexed by $i = 1, 2, \ldots, n$. Part of the output of sector i is consumed domestically (c_2^i), part of it is exported (x_2^i). These sectors are called exposed. Each individual sector can consist of differently behaving firms but producing a homogeneous commodity. We allow for the case that the exposed sector consists of small number of firms (including a single firm) and of a large number of firms. Another distinction made is between the country being "large" or "small" on the market of an exported commodity. All individual firms producing a variety for which the economy is small, can be aggregated and described as a representative competitive firm. Some of the "large" sectors each may contain a continuum of competitive firms, which we aggregate into a representative firm as well. Each of the other "large" sectors consists of a finite number of firms exploiting their market power. The different market structures to be discussed all differ in the specification and composition of the exposed sector. Hence, for each case the details of the sector receive due attention. For sector i the technology is described by F_2^i, with as inputs capital (k_2^i) and a raw material (z_2^i). The third consumer commodity cannot be produced domestically; it needs to be imported. Consumption is denoted by c_3. The third commodity is taken as the numéraire. Capital is immobile internationally but mobile between domestic sectors. Some empirical as well as theoretical support for the assumption of international immobility of capital can be found in Gordon and Bovenberg (1996). The economy's endowment is given by k. The rate of return on capital is denoted by r.

The raw material is in principle freely available in unlimited amounts. However, processing of the raw material causes pollution, proportional to production, with factor of proportionality equal to unity. Contrary to Copeland and Taylor (2003) both sectors are polluting. Pollution is damaging. The government therefore levies taxes τ_1 and τ_2^i ($i = 1, 2, \ldots, n$) per unit of raw material used in the sheltered and the exposed sectors, respectively. The taxes can be differentiated between as well as within sectors. The tax revenues are recycled to the consumers in a lump sum fashion. Alternatively, the government imposes emission ceilings, that might or might not be implemented through a system of tradable permits.

The income of the representative *consumer* consists of the value of the capital endowment rk, the tax revenues $\tau_1 z_1 + \sum_{i=1}^n \tau_2^i z_2^i$, and the profits of the firms, which amount to $p_1 F_1(k_1, z_1) - rk_1 - \tau_1 z_1$ and $\sum_{i=1}^n \{p_2^i F_2^i(k_2^i, z_2^i) - rk_2^i - \tau_2^i z_2^i\}$ for the sheltered and the exposed sectors, respectively, assuming for the moment that the domestic price of the second commodity equals its world market price. Under the assumption of full employment of capital (in a situation where firms maximize profits) total income boils down to (in shorthand) $p_1 F_1 + \sum_{i=1}^n p_2^i F_2^i$.

The consumer maximizes utility, taking prices and income given. Preferences consist of two parts. First, they depend on the consumption of the consumer goods. This is represented by a utility function, denoted by $U(c_1, c_2, c_3)$, where $c_2 = (c_2^1, c_2^2, \ldots, c_2^n)$. The utility function is assumed to have all the usually desired properties such as concavity, differentiability and monotonicity. Second, consumers experience damage from pollution. With a little abuse of notation, this part of the preferences is given by the (convex and increasing) damage function

$$D(z_1, z_2) = D\left(z_1 + \sum_{i=1}^n z_2^i\right), \quad \text{with } z_2 = (z_2^1, z_2^2, \ldots, z_2^n).$$

So, it is assumed that pollution is only local. Total social welfare is

$$W(c_1, c_2, c_3, z_1, z_2) = U(c_1, c_2, c_3) - D(z_1, z_2).$$

Finally, we impose equilibrium on the current account of the balance of payments. Summarizing:

$$c_1 = F_1(k_1, z_1), \tag{11}$$

$$c_2^i = \sum_{i=1}^{n} [F_2^i(k_2^i, z_2^i) - x_2^i], \quad i = 1, 2, \dots, n, \tag{12}$$

$$c_3 = \sum_{i=1}^{n} p_2^i x_2^i, \tag{13}$$

$$k_1 + \sum_{i=1}^{n} k_2^i = k. \tag{14}$$

Demand for the exported commodity is still to be specified. It depends on the market structure under consideration.

In the sequel we will occasionally employ specific functional forms to illustrate the results and to perform numerical exercises. In those exercises utility is logarithmically additive, environmental damage is quadratic, production functions are Cobb–Douglas.

$$U(c_1, c_2, c_3) = \ln c_1 + \ln c_2 + \ln c_3, \tag{15}$$

$$F_1(k_1, z_1) = k_1^{\alpha} z_1^{1-\alpha}, \tag{16}$$

$$F_2^i(k_2^i, z_2^i) = (k_2^i)^{\beta} (z_2^i)^{1-\beta}, \tag{17}$$

$$D(z_1, z_2) = 1/2 \left[z_1 + \sum_{i=1}^{n} z_2^i \right]^2. \tag{18}$$

3.3 First-Best; Perfect Competition and the Large Country Case

In this section, we characterize the social optimum for the case of perfect competition as well as for the case of a large country. With perfect competition each of the producers in the exposed sector takes the world market price as given. The world market price is also equal to the domestic price. The large country case can be modeled in several ways. One can maintain the assumption of a continuum of price taking producers in an exposed sector but in addition assume that the government can exploit the fact that the country as a whole is a large player on the world market. Alternatively, it can be assumed that there is a single exporting firm of the commodity for which the country is large, that exploits its monopoly power itself. We go into both alternative settings.

The first-best optimum is defined as the allocation that maximizes social welfare, i.e., utility of the representative agent minus the disutility of pollution damage, subject to the restrictions imposed by the technology and the condition of equilibrium on the current account of the balance of payments. In mathematical terms it is the solution of the maximization of

$$W(c_1, c_2, c_3, z_1, z_2) = U(c_1, c_2, c_3) - D\left(z_1 + \sum_{i=1}^{n} z_2^i\right),$$

subject to (11)–(14). The Lagrangian of the problem reads:

$$\begin{aligned} L = \; & U(c_1, c_2, c_3) - D\left(z_1 + \sum_{i=1}^{n} z_2^i\right) + \mu_1[F_1(k_1, z_1) - c_1] \\ & + \sum_{i=1}^{n} \mu_2^i [F_2^i(k_2^i, z_2^i) - x_2^i(p_2^i) - c_2^i] \\ & + \mu_3\left[\sum_{i=1}^{n} p_2^i x_2^i(p_2^i) - c_3\right] + \bar{r}\left[k - k_1 - \sum_{i=1}^{n} k_2^i\right], \end{aligned}$$

where $x_2^i(p_2^i)$ denotes world demand for variety i.

Assuming an interior solution we find as necessary conditions

$$\frac{\partial U}{\partial c_1} = \mu_1; \quad \frac{\partial U}{\partial c_2^i} = \mu_2^i, \quad i = 1, 2, \ldots, n; \quad \frac{\partial U}{\partial c_3} = \mu_3, \tag{19}$$

$$\mu_1 \frac{\partial F_1}{\partial k_1} = \bar{r}; \quad \mu_1 \frac{\partial F_1}{\partial z_1} = D', \tag{20}$$

$$\mu_2^i \frac{\partial F_2^i}{\partial k_2^i} = \bar{r}; \quad \mu_2^i \frac{\partial F_2^i}{\partial z_2^i} = D', \quad i = 1, 2, \ldots, n, \tag{21}$$

$$-\mu_2^i \frac{dx_2^i}{dp_2^i} + \mu_3\left[x_2^i(p_2^i) + p_2^i \frac{dx_2^i}{dp_2^i}\right] = 0, \tag{22}$$

where primes refer to derivatives. In the sequel hats denote the solution of this problem: $(\hat{c}_1, \hat{c}_2, \hat{c}_3, \hat{p}_2, \hat{k}_1, \hat{k}_2, \hat{z}_1, \hat{z}_2, \hat{x}_2)$, where $k_2 = (k_2^1, k_2^2, \ldots, k_2^n)$, $z_2 = (z_2^1, z_2^2, \ldots, z_2^n)$, $x_2 = (x_2^1, x_2^2, \ldots, x_2^n)$ and $p_2 = (p_2^1, p_2^2, \ldots, p_2^n)$.

The interpretation of the necessary conditions is straightforward. With μ_1 the marginal value (in utility terms) of one unit of output of the sheltered sector, the second part of (20) says that the marginal value of a pollution input in this sector should equal marginal damage (disutility of pollution). This also holds for the exposed sectors, with μ_2^i interpreted as the marginal value of a unit of variety i. Equation (22) says that an increase of the world market price of variety i causes lower demand, so that more output can be used for domestic consumption, which is beneficial. But the export revenues decrease, implying less income available for the import of the third commodity.

The next step is to investigate how the first-best optimum can be realized in a decentralized setting. Many results regarding the implementation of the first-best optimum in a decentralized economy are straightforward modifications of earlier work by, for instance, Hoel (1996) and Rauscher (1997), and they have become standard inferences in the theory of international trade (see e.g., Dixit 1985). Nevertheless, we state them explicitly here for later reference. Define

$$t^i = -\frac{1}{\hat{\varepsilon}_2^i}, \quad p_1 = \frac{\hat{\mu}_1}{\hat{\mu}_3}, \quad q_2^i = \frac{\hat{\mu}_2^i}{\hat{\mu}_3} = p_2^i(1-t^i), \quad (i = 1, 2, \ldots, n), \quad p_3 = 1,$$
$$\tau = \tau_1 = \tau_2^i = \frac{D'(\hat{z})}{\hat{\mu}_3}, \quad (i = 1, 2, \ldots, n), \quad r = \frac{\hat{\hat{r}}}{\hat{\mu}_3}$$

with $\hat{\varepsilon}_2^i$ is the price elasticity of world market demand for the second commodity which, evaluated at the optimum (smaller than minus unity). So, q_2^i is the value in monetary terms of variety i. Due to the concavity/convexity assumptions on the functions involved the necessary conditions corresponding with the first-best social optimum are also sufficient. Observe the following:

– The pair $(\hat{k}_1, \hat{z}_1)$ maximizes profits $p_1 F_1(k_1, z_1) - rk_1 - \tau z_1$ of (aggregate) firm 1. This is the case because in the first-best the pair maximizes

$$\hat{\mu}_3 \left[\frac{\hat{\mu}_1}{\hat{\mu}_3} F_1(k_1, z_1) - \frac{\hat{\hat{r}}}{\hat{\mu}_3} k_1 - \frac{D'(z)}{\hat{\mu}_3} z_1 \right].$$

– For the same reason $(\hat{k}_2^i, \hat{z}_2^i)$ maximizes profits $q_2^i F_2^i(k_2^i, z_2^i) - rk_2^i - \tau z_2^i$ of (aggregate) firm i of the exporting sector.
– The triple $(\hat{c}_1, \hat{c}_2, \hat{c}_3)$ maximizes $U(c_1, c_2, c_3)$ subject to

$$p_1 c_1 + \sum_{i=1}^{n} q_2^i c_2^i + p_3 c_3 = p_1 F_1 + \sum_{i=1}^{n} q_2^i F_2^i + T,$$

where T denotes recycled export tariff revenues.
– The world market p_2^i maximizes $(p_2^i - q_2^i) x_2^i (p_2^i)$: export revenues minus the opportunity costs of consumption of the exported commodity foregone.
– Finally, all markets clear at the proposed prices.

Hence, we can state the following:

The first-best optimum can be implemented in a decentralized economy by:

(i) Imposing a uniform emission tax.
(ii) Imposing export taxes on the firms in sectors where the economy is "large" but where the individual firms do not exploit this.
(iii) Correcting non-environmental domestic distortions.

This result about implementation is well known from the general theory of international trade (see also Neary 2006). It implies that in the case of perfect competition on the world market for the exported commodity, it is optimal not to impose an import tariff ($t^i = 0$ if $\hat{\varepsilon}^i = -\infty$) and to tax emissions according to their marginal damage. Hence, with a uniform Pigouvian emission tax the social optimum can be reached in a trading economy. The situation is different when the country is "large", so that world demand depends on the price set by the country (assuming for the moment there is no perceived interaction with other foreign players). If, as is commonly assumed in the literature, each individual domestic firm is small on the world market, but that the sector producing the exported commodity, is large on aggregate, then it is optimal to impose an export tax, but still tax emissions according to marginal damage, which is equal for all firms. Finally, if firms are large and act as such on the world market, there is clearly no need for an export levy. But, if these firms act non-competitively on the home market, a correction of this externality is in order.

One may also think of a situation with an upper bound $\bar{z}$ on total pollution, imposed by e.g., an international treaty. Hence the constraint to the optimization problem is $z_1 + \sum_{i=1}^{n} z_2^i \leq \bar{z}$. If social welfare includes pollution damage and if the emission constraint would not be binding in the optimum, adding the constraint is not interesting. So, we assume that the ceiling is binding. In order to comply with the international norm, the government may levy emission taxes τ_1 and τ_2^i $(i = 1, 2, \ldots, n)$ per unit of raw material input in all sectors of the economy. It is easy to see that the setting does not change the way the optimum can be implemented in a decentralized economy by means of taxes. Alternatively, the government may install a system of tradable emissions permits. Such a system is called *uniform* if trade is allowed among all domestic sectors, including the sheltered sector. The system is *differentiated* if individual sectors have their own system, with trade limited to those firms belonging to the individual sectors. Differential environmental policy across sectors is not needed if the country is small on all world markets, if its individual firms exploit their monopoly power, or if the government can levy an export tax on "large" but competitive sectors. We will return to emission caps in subsection 5.4.

3.4 Second-Best in the Large Country Case

We now assume that, due to international regulations, it is not feasible to use tariffs as an instrument. It has been shown above that trade tariffs are not needed to implement the first-best optimum if there is perfect competition. Therefore, our attention will be restricted to the large country case. In order to avoid the necessity of correction of externalities on the domestic output markets, we will assume that all individual firms are price takers, or that they do not supply to the home market. The question addressed is again whether it is optimal to differentiate between domestic sectors with respect to the emission taxes and whether taxes are below the marginal damage or not.

Suppose the government has set Pigouvian emission taxes; they equal marginal damage ($\tau = D'/(\partial U/\partial c_3)$) and are uniform over the sectors. We first investigate the question how social welfare changes if the government marginally deviates from this policy, given the market behavior of individual agents. For the case of individually price taking firms we have

$$
\begin{aligned}
dW &= \frac{\partial U}{\partial c_1}dc_1 + \sum_{i=1}^{n}\frac{\partial U}{\partial c_2^i}dc_2^i + \frac{\partial U}{\partial c_3}dc_3 - D'\left[dz_1 + \sum_{i=1}^{n}dz_2^i\right] \\
&= \frac{\partial U}{\partial c_3}\left[p_1 dc_1 + \sum_{i=1}^{n}p_2^i dc_2^i + dc_3 - \tau\left[dz_1 + \sum_{i=1}^{n}dz_2^i\right]\right] \\
&= \frac{\partial U}{\partial c_3}\left[p_1\left\{\frac{\partial F_1}{\partial k_1}dk_1 + \frac{\partial F_1}{\partial z_1}dz_1\right\} + \sum_{i=1}^{n}p_2^i\left\{\frac{\partial F_2^i}{\partial k_2^i}dk_2^i + \frac{\partial F_2^i}{\partial z_2^i}dz_2^i - \frac{dx_2^i(p_2^i)}{dp_2^i}dp_2^i\right\}\right. \\
&\quad \left. + \sum_{i=1}^{n}\left\{x_2^i(p_2^i)dp_2^i + p_2^i\frac{dx_2^i(p_2^i)}{dp_2^i}dp_2^i\right\} - \tau\left[dz_1 + \sum_{i=1}^{n}dz_2^i\right]\right] \\
&= \frac{\partial U}{\partial c_3}\sum_{i=1}^{n}x_2^i(p_2^i)dp_2^i = \frac{\partial U}{\partial c_3}\sum_{i=1}^{n}x_2^i(p_2^i)\frac{dp_2^i}{d\tau}d\tau.
\end{aligned}
$$

For all sectors that behave as large sectors by themselves we have $dc_2^i = 0$ and $dp_2^i x_2^i(p_2^i) = rdk_2^i + \tau dz_2^i$. Hence

$$
dW = \frac{\partial U}{\partial c_3}\sum_{i}x_2^i(p_2^i)\frac{\partial p_2^i}{\partial \tau}d\tau,
$$

where the summation is taken over the competitive sectors. It is welfare improving to increase the emission tax for these competitive sectors since the higher tax will decrease supply, thereby raising the price (see also Krutilla 1991). Therefore, the higher emission tax helps to reduce overall pollution. This result obviously also holds in case of an exogenous upper bound on pollution. Marginally decreasing or increasing the tax on emissions in the sheltered sector does not yield higher social welfare. To see this, observe that in equilibrium $p_1\frac{\partial F_1}{\partial z_1} = \tau_1$ from profit maximization in the sheltered sector. Moreover, $\frac{\partial U}{\partial c_1} = p_1\frac{U}{\partial c_3}$. Therefore $\frac{\partial U}{\partial c_1}\frac{\partial F_1}{\partial z_1} = \tau_1\frac{\partial U}{\partial c_3}$. Consider a marginal variation of z_1 only. In an optimum, this variation should not allow for a welfare improvement. Hence

$$
\frac{d}{dz_1}\left[U(c_1, c_2, c_3) - D\left(z_1 + \sum_{i=1}^{n}z_2^i\right)\right] = 0.
$$

Stated otherwise

$$
\frac{\partial U}{\partial c_1}\frac{\partial F_1}{\partial z_1} = \tau_1\frac{\partial U}{\partial c_3} = D'.
$$

In what follows we shall perform a *global* analysis of the problem. This allows for a calculation of globally optimal environmental taxes, rather than calculating the effect of a marginal deviation from taxes equal to marginal damage. Global welfare optimization on the part of the government boils down to the maximization of utility minus damage, taking the constraints outlined above into account. We use the functional forms introduced in subsection 3.1. World demand is isoelastic: $x_2(p_2) = p_2^{\varepsilon}$ ($\varepsilon < 0$). It follows from utility maximization subject to the budget constraint that

$$p_1c_1 = p_2c_2 = c_3 = \frac{1}{3}[p_1F_1 + p_2F_2]. \tag{23}$$

Together with the conditions for market equilibrium, i.e., $F_1 = c_1,\ F_2 = c_2 + x(p_2)$, this yields:

$$p_1c_1 = p_2x(p_2), \quad c_2 = x(p_2), \quad c_3 = p_2x(p_2). \tag{24}$$

It follows from profit maximization that equilibrium prices are on the factor price frontiers, corresponding with zero profits, defined by:

$$p_1 = \left(\frac{r}{\alpha}\right)^{\alpha}\left(\frac{\tau_1}{1-\alpha}\right)^{1-\alpha} = f_1(r,\tau_1), \tag{25}$$

$$p_2 = \left(\frac{r}{\beta}\right)^{\beta}\left(\frac{\tau_2}{1-\beta}\right)^{1-\beta} = f_2(r,\tau_2). \tag{26}$$

Factor demands are:

$$k_1(r,\tau_1,p_1,p_2) = \left(\frac{r}{\alpha}\right)^{\alpha-1}\left(\frac{\tau_1}{1-\alpha}\right)^{1-\alpha}F_1 = \left(\frac{r}{\alpha}\right)^{\alpha-1}\left(\frac{\tau_1}{1-\alpha}\right)^{1-\alpha}\frac{p_2x(p_2)}{p_1}, \tag{27}$$

$$z_1(r,\tau_1,p_1,p_2) = \left(\frac{r}{\alpha}\right)^{\alpha}\left(\frac{\tau_1}{1-\alpha}\right)^{-\alpha}F_1 = \left(\frac{r}{\alpha}\right)^{\alpha}\left(\frac{\tau_1}{1-\alpha}\right)^{-\alpha}\frac{p_2x(p_2)}{p_1}, \tag{28}$$

$$k_2(r,\tau_2,p_2) = \left(\frac{r}{\beta}\right)^{\beta-1}\left(\frac{\tau_2}{1-\beta}\right)^{1-\beta}F_2 = \left(\frac{r}{\beta}\right)^{\beta-1}\left(\frac{\tau_2}{1-\beta}\right)^{1-\beta}2x(p_2), \tag{29}$$

$$z_2(r,\tau_2,p_2) = \left(\frac{r}{\beta}\right)^{\beta}\left(\frac{\tau_2}{1-\beta}\right)^{-\beta}F_2 = \left(\frac{r}{\beta}\right)^{\beta}\left(\frac{\tau_2}{1-\beta}\right)^{-\beta}2x(p_2). \tag{30}$$

Straightforward manipulations, using $k_1 + k_2 = k$, yield

$$k_1 = \frac{\alpha k}{\alpha + 2\beta}, \quad k_1 = \frac{2\beta k}{\alpha + 2\beta}.$$

After substitution we have

$$W = \ln k_1^{\alpha}z_1^{1-\alpha} + \ln\frac{1}{2}k_2^{\beta}z_2^{1-\beta} + \ln\left(\frac{1}{2}k_2^{\beta}z_2^{1-\beta}\right)^{1+1/\varepsilon} - \frac{1}{2}[z_1+z_2]^2.$$

Maximization with respect to z_1 and z_2 gives

$$z_1 = (1-\alpha)/\sqrt{(1-\alpha)+(1-\beta)(2+1/\varepsilon)},$$
$$z_2 = (1-\beta)(2+1/\varepsilon)/\sqrt{(1-\alpha)+(1-\beta)(2+1/\varepsilon)}.$$

Then, from the fact that

$$\frac{\tau_1 z_1}{\tau_2 z_2} = \frac{(1-\alpha)p_1 F_1}{2(1-\beta)p_1 F_1},$$

it follows that

$$\tau_2 = \frac{2}{2 + 1/\varepsilon}\tau_1 > \tau_1.$$

So, for these specifications it is optimal to set the emissions tax higher for the exposed sector than for the sheltered one, not only locally, but also globally.

The same result is obtained in case there is an exogenous upper bound on total emissions. A tradable permits system should then be dual, allowing for a separate permits market in each sector, yielding different permit prices for the two sectors. In an unconstrained tradable permits system the exposed sector would demand more emission permits and supply more to the world market than is optimal. In the case of more than one export sector, multiple separate sectoral permits markets should be established. This policy is generally more difficult to implement, and it will be intricate to ensure perfect competition as well. A policy design based on differentiated emissions taxes is therefore likely to be more appropriate.

4 OLIGOPOLY; PARTIAL EQUILIBRIUM

4.1 Introduction

In this section, we start with a brief survey of the previous literature on oligopoly. The analysis takes place within a partial equilibrium framework along the lines developed by Conrad (1993), Kennedy (1994) and Barrett (1994). Then we develop and study a simplified partial equilibrium model that serves as a benchmark for the general equilibrium approach of the next section. A distinction will be made between Cournot and Bertrand.

The basic idea in all the contributions discussed here goes back to the Brander and Spencer (1985) model where governments can take actions that constitute a commitment of domestic firms toward their competitors. In a two-stage game interpretation the government makes a strategic choice before the domestic firm takes an action with regard to price setting. In the environmental policy literature both taxes and standards predominantly act as a precommitment device for the government. A discussion of other precommitment devices, like subsidies on R&D instrument, and their consequences can be found in amongst others, Ulph (1996).

4.2 The Kennedy/Conrad/Barrett models

In this section, most attention is paid to Kennedy's (1994) contribution because it sketches the most general setting. Kennedy (1994) analyses a model that includes many of the elements that play a crucial role in the remainder of this survey. It is a two-country model, where each country has n identical firms, producing a homogeneous commodity. Production of the representative firm in the home country is y, and it exports x. The inverse domestic demand function reads $p(c) = p(ny - nx + nx^f)$, where x^f denotes the exports of the representative foreign firm. The foreign domestic demand function reads $p(c^f) = p(ny^f - nx^f + nx)$. Marginal production costs are ϑ. Pollution is an inevitable by-product of production. Emissions by the representative home firm are $z = y/\vartheta$. The parameter ϑ is chosen by each individual firm. Pollution damage in the home country is $D(z, z^f) = D(nz + \chi nz^f)$. This specification allows for transboundary pollution: fraction χ of foreign emissions is deposited in the home country, and vice versa. Emissions are taxed at a rate τ. Profits of the representative firm read

$$\pi(y, x, \vartheta) = p(c)[y - x] + p(c^f)x - \vartheta y - \tau y/\vartheta$$

with

$$\begin{aligned} c &= y - x + (n-1)[\bar{y} - \bar{x}] + nx^f, \\ c^f &= n[y^f - x^f] + x + (n-1)\bar{x}, \end{aligned}$$

where $\bar{y}$ and $\bar{x}$ denote output and net exports of each competing domestic firm, taken as given. When determining optimal production, export and cost parameter, the firm also takes foreign exports as given. The necessary conditions for an individual optimum read

$$\frac{\partial \pi}{\partial y} = 0 : p'(c)[y - x] + p(c) = \left(\vartheta + \frac{\tau}{\vartheta}\right), \tag{31}$$

$$\frac{\partial \pi}{\partial x} = 0 : -p'(c)[y - x] - p(c) + p'(c^f)x + p(c^f) = 0, \tag{32}$$

$$\frac{\partial \pi}{\partial \vartheta} = 0 : \vartheta = \sqrt{\tau}. \tag{33}$$

The Nash equilibrium is symmetric. All firms, be it domestic or foreign, are subject to the same emission tax. Hence they will choose the same abatement technology, and all outputs are identical. Moreover, $c = c^f$. It follows from (32) that $x = \frac{1}{2}y$. Then we have

$$2np + cp' = 4nt. \tag{34}$$

The social optimum can be formulated as the outcome of the maximization of the sum of each country's consumer surplus, producer surplus and tax revenues, minus pollution damage

$$\begin{aligned} W + W^f &= U(c) - p(c)c + p(c)[ny - nx] + p(c^f)nx - \vartheta ny - \tau\frac{ny}{\vartheta} + \tau\frac{ny}{\vartheta} \\ &\quad - D\left(\frac{ny}{\vartheta} + \chi\frac{ny^f}{\vartheta^f}\right) + U(c^f) - p(c^f)c^f + p(c^f)[ny^f - nx^f] + p(c)nx^f \\ &\quad - \vartheta^f ny^f - \tau^f\frac{ny^f}{\vartheta^f} + \tau^f\frac{ny^f}{\vartheta^f_i} - D\left(\frac{ny^f}{\vartheta^f} + \chi\frac{ny}{\vartheta}\right) \\ &= 2\left[U(ny) - tny - D\left((1+\chi)\frac{ny}{t}\right)\right], \end{aligned}$$

where it has been taken into account that the emission tax will be uniform over the countries. Moreover, (33) has already been incorporated. A necessary condition for optimality is

$$[p - t]\frac{\partial ny}{\partial t} - ny = \frac{1+\chi}{t^2}D'\left[t\frac{\partial ny}{\partial t} - ny\right]. \tag{35}$$

If markets were perfectly competitive then $\frac{\partial ny}{\partial t} = 0$ and $\tau = (1+\chi)D'$ so that the emission tax would equal marginal damage. By using (34) it can be shown that in the case of oligopoly the optimal tax rate is smaller than marginal damage. Finally, Kennedy studies the situation where the two governments play a Nash game against each other.[2] A government sets its own tax rate, and takes the other government's tax rate as well as firms' behavior as given. The reaction function for the home country is $p + \frac{1}{2}p'y = 2t$. In equilibrium, we have $2np + p'c = 2n(t + t^f)$, where f refers to the foreign country. Each country is assumed to be able to calculate the change in the equilibrium upon a change in its own tax rate, given that the other country's tax rate remains unchanged. It is argued that in the Nash equilibrium the emission tax is below the efficient one given by (31). Three elements play a role.

First, the so-called transboundary externality effect is responsible for a too low emission tax, at least if pollution is transboundary.

Second, a rent capture effect occurs. A unilateral decrease of the emission tax, starting from the efficient one, in one country will boost net exports, because it has a greater impact on production than on domestic consumption. Also the rent capture effect calls for lower environmental taxation.

The third effect is brought about by the pollution shifting. A decrease of the tax rate will increase domestic production and thereby pollution. Obviously, the effect is necessarily zero if pollution is purely transboundary. If it is only partly transboundary then the effect is positive. Therefore, there would be an incentive to increase the local taxes. It is formally shown by Kennedy that the second effect dominates the third one. Hence the overall result is a tax rate below the efficient one, in both countries.

Conrad (1993) studies a two-country world, within each country a single firm producing a homogeneous commodity that is sold on a third market only. So, domestic consumption is not taken into account. Pollution is purely global and uniformly mixing. Each firm has the disposal of an abatement technology. Conrad shows that the pollution tax rate in the Nash equilibrium is below the tax rate that would emerge under social welfare maximization, taking into account the fact that pollution is transboundary. This is what one would expect, since the model is less general than Kennedy's. However, Conrad also makes another contribution by considering other policy instruments such as a subsidy on abatement activities. This subsidy, together with a high emission tax, might be welfare improving, compared with the case where subsidies are absent. In any case, abatement is enhanced.

Also Barrett (1994) is one of the forerunners on oligopoly and strategic environmental policy. His model resembles Conrad's in the sense that the two oligopolists in two countries produce for a third market only. But in his model, a standard is the policy instrument and pollution is purely local. In the policy games played by the two governments, emission standards are set below standards corresponding with marginal

[2] The mathematics is not reproduced here.

damage in the case of Cournot competition, and with standards higher than marginal damage when competition is Bertrand. So, with Cournot competition policy is too lax, and with Bertrand competition policy is too strict. When domestic output is produced by multiple firms, these results do not necessarily hold anymore, and the standards might be too lax or too stringent. We will return to the Barrett model in the sequel.

4.3 Partial Equilibrium Cournot Competition

We will argue in Section 5 that the policy recommendations following from a partial equilibrium approach might drastically differ from those derived in a general equilibrium. This will be illustrated by means of an oligopoly model closely related to the ones discussed in the previous subsection. To make the point we employ a model that in some respects is simpler than those discussed above. We abstract from transboundary pollution, and from the presence of an abatement technology. We also restrict ourselves to a third market on which all production of the exposed sector is sold. There is no great loss in looking at local pollution only. It should be clear from the previous subsection what the effect of transboundary pollution is. Neglecting abatement is more serious. It is assumed that there is a polluting input, so that in the case of standards this would just mean an upper bound on the use of the production factor, whereas taxes have basically the same effect. In this way, by not incorporating abatement as a potential activity to which resources can be devoted, we reach a considerable simplification, without loosing the need for environmental policy. The absence of the home market is in the spirit of earlier work by Conrad (1993) and Barrett (1994). In the present subsection, we introduce the model with Cournot competition.

In the partial equilibrium approach the government takes as given all that occurs in the domestic sheltered sector. The government is not interested in total social welfare per se: e.g., pollution damage caused by the sheltered domestic sectors is not taken into account. In this setting, social welfare can be written as

$$W = \sum_{i=1}^{n} \{ p(x, x^f)x^i - \tau^i z^i \} - D(z) + \sum_{i=1}^{n} \tau^i z^i .$$

Here $p(x, x^f) = p(x^1, x^2, \ldots, x^n, x^f) = p(\sum_{i=1}^{n} (x^i + x^f))$ is the world market price of the (homogeneous) exported commodity, depending on output x^i of sector i ($i = 1, 2, \ldots, n$) and foreign supply x^f. Emissions by sector i are z^i, taxed at the rate τ^i is the emission tax. We have $x^i = F^i(z^i)$. There is one foreign supplier of the exported commodity. Damage is $D(z) = D(z^1, z^2, \ldots, z^n) = D(\sum_{i=1}^{n} z^i)$. Hence, the government seeks to maximize export revenues minus social costs, the latter consisting of capital costs (which are exogenous) and the external damage costs caused by emissions of the exporting sector. All emission tax revenues $\sum_{i=1}^{n} \tau^i z^i$ are recycled to the consumer.

In Barrett's Nash game each government takes output of domestic firms as given. In such circumstances the socially optimal standard arises from the equality of marginal abatement costs and marginal damage. Implementation of this rule requires information about the abatement cost function. In our model, with taxes and in the absence of abatement, an analogous approach would be to assume that the government knows the cost function or the production function, from which demand for the raw material (and hence emissions) can be derived. Profit maximization on the part of firm i implies

$$\{p + p'x^i\}\frac{\partial F^i}{\partial z^i} = \tau^i, \quad i = 1, 2, \ldots, n. \tag{36}$$

We first perform a local analysis, starting from a situation where the government sets the emission tax equal to marginal damage: $\tau^i = D'$. From $dx^i = \frac{\partial F^i}{\partial z^i} dz^i$ and (36) we have $\tau^i dz^i = [p + p'x^i]dx^i$. Hence

$$\begin{aligned}
dW &= \sum_{i=1}^{n} [x^i dp + p dx^i] - D'(z) \sum_{i=1}^{n} dz^i, \\
&= x^1 p' \left\{ \sum_{i=1}^{n} dx^i + dx^f \right\} + p dx^1 - D' dz^1 + x^2 p' \left\{ \sum_{i=1}^{n} dx^i + dx^f \right\} \\
&\quad + p dx^2 - D' dz^2 + \cdots + x^n p' \left\{ \sum_{i=1}^{n} dx^i + dx^f \right\} + p dx^n - D' dz^n, \\
&= x^1 p' \{dx^2 + dx^3 + \cdots + dx^n\} + x^2 p' \{dx^1 + dx^3 + \cdots + dx^n\} \\
&\quad + \cdots + x^n p' \{dx^1 + dx^2 + \cdots + dx^{n-1}\} + \sum_{i=1}^{n} x^i p' dx^f, \\
&= \left(\sum_{i=1}^{n} x^i - x^1 \right) p' dx^1 + \left(\sum_{i=1}^{n} x^i - x^2 \right) p' dx^2 + \cdots + \left(\sum_{i=1}^{n} x^i - x^n \right) p' dx^n \\
&\quad + \left(\sum_{i=1}^{n} x^i \right) p' dx^f.
\end{aligned}$$

For identical domestic firms we have $dW = n(n-1)\tilde{x}p'd\tilde{x} + n\tilde{x}p'dx^f$, where $\tilde{x}$ is supply of the representative domestic producer. So, if dx^f is assumed to be zero, it is optimal to increase the tax in order to decrease supply and enhance social welfare.

Assume there is one domestic producer. Then

$$dW = xp'dx^f = xp' \frac{dx}{d\tau} \frac{dx^f}{dx} d\tau. \tag{37}$$

If the policy maker assumes that a change in its policy does not affect foreign supply ($dx^f = 0$), it is optimal to keep the tax at the so-called environmentally optimal level. In the right-hand side of (37) several factors appear. Clearly $x > 0$ and $p' < 0$. Moreover, $dx/d\tau < 0$ since the reaction curve of the domestic firm shifts outward as the tax rate decreases (this is a consequence of the second order condition for the maximization of profits by the domestic firm). If the Nash equilibrium on the product market is stable, and if the policy maker takes into account that the outward shift of the domestic reaction curve leads to an equilibrium with smaller foreign supply, the policy maker sets the emission tax below marginal damage.

With multiple domestic producers ($n > 1$) it might be optimal to have higher emission taxes, because two types of impacts can be distinguished due to a decrease in the emission tax rate. On the one hand, production increases, thereby enhancing profits from exports on the world market due to the fact that foreign equilibrium supply decreases, as before. On the other hand, the increase of supply by the domestic firms may decrease their profitability on the world market. The total effect is therefore ambiguous. Barrett (1994) and Ulph (1997), who employ a somewhat different model, find the same result.

In order to illustrate the results obtained above we return to the example of a Cobb–Douglas technology and a quadratic damage function of subsection 3.1 in the previous section, with a linear demand function. There is only a single domestic producer. Demand for the raw material is

$$z = \left(\frac{r}{\beta}\right)^{\beta} \left(\frac{\tau}{1-\beta}\right)^{-\beta} x,$$

where r is to be considered fixed. Without strategic behavior on the part of the government the emission tax rate equals marginal damage: $\tau = D'(z) = z$. Combining the two equations, we get a relationship between the emission tax and output:

$$\tau = \left(\frac{r}{\beta}\right)^{\frac{\beta}{1+\beta}} \left(\frac{1}{1-\beta}\right)^{\frac{-\beta}{1+\beta}} x^{\frac{1}{1+\beta}}.$$

Paraphrasing Barrett, this schedule can be called the *environmentally optimal emission tax*.

For each given tax rate the exporting firm maximizes its profits with respect to the raw material, yielding

$$1 - 2ax - ax^{f} = \left(\frac{\tau}{1-\beta}\right)^{1-\beta} \left(\frac{r}{\beta}\right)^{\beta}.$$

Note that the reaction curve is downward sloping for all tax rates. The next question is what happens when the government decreases the emission tax, starting from the "*environmentally optimal*" one defined above. Clearly, given the foreign country's output, the domestic firm's reaction curve shifts outward and the new equilibrium has higher domestic production and less foreign production, assuming a stable Nash equilibrium on the output market. What is the implication for social welfare? According to (37) we have

$$\frac{dW}{d\tau} = -ax\frac{dx^{f}}{dx}\frac{dx}{d\tau}.$$

Taking into account that

$$\frac{dx}{d\tau} < 0 \quad \text{and} \quad \frac{dx^{f}}{dx} < 0,$$

we conclude that it is indeed optimal for the government to set an emission tax lower than the environmentally optimal one. This is not only true under the assumption that the foreign government does not react strategically, but the conclusion holds as well if the foreign government does react strategically.

4.4 Partial Equilibrium Bertrand Competition

Next we consider Bertrand oligopoly on the world markets. We maintain the assumption that there is only one foreign competitor, charging a price p^f. Social welfare reads

$$W = \sum_{i=1}^{n} \{ p^i x^i(p, p^f) - \tau^i z^i \} - D(z) + \sum_{i=1}^{n} \tau^i z^i,$$

where $p = (p^1, p^2, \ldots, p^n)$ is the vector of prices charged by the domestic firms, and $x^i = F^i(z^i)$. Firm i maximizes profits, $p^i F^i(z^i) - \tau^i z^i$, subject to $F^i(z^i) = x^i(p, p^f)$. This yields

$$\left\{ p^i + x^i \frac{1}{\partial x^i / \partial p^i} \right\} \frac{\partial F^i}{\partial z^i} = \tau^i, \quad i = 1, 2, \ldots, n. \tag{38}$$

Taking into account profit maximization, $F^i(z^i) = x^i(p, p^f)$ and $\tau^i = D'(z)$ the variation in social welfare is

$$\begin{aligned} dW &= \sum_{i=1}^{n} \{ x^i dp^i + p^i dx^i \} - D'(z) \sum_{i=1}^{n} dz^i \\ &= \sum_{i=1}^{n} \left\{ x^i dp^i + p^i \frac{\partial F^i}{\partial z^i} dz^i - D' dz^i \right\} \\ &= \left\{ x^1 - \sum_{j=1}^{n} x^1 \frac{\partial x^j / \partial p^1}{\partial x^j / \partial p^j} \right\} dp^1 + \left\{ x^2 - \sum_{j=1}^{n} x^2 \frac{\partial x^j / \partial p^2}{\partial x^j / \partial p^j} \right\} dp^2 \\ &\quad + \cdots + \left\{ x^n - \sum_{j=1}^{n} x^n \frac{\partial x^j / \partial p^n}{\partial x^j / \partial p^j} \right\} dp^n - \sum_{j=1}^{n} x^j \frac{\partial x^j / \partial p^f}{\partial x^j / \partial p^j} dp^f. \end{aligned}$$

As in the case of Cournot competition the result is ambiguous if there is more than one domestic supplier. Therefore, we assume that $n = 1$. Then

$$dW = -x \frac{dp}{dp^f} \frac{dp^f}{d\tau} d\tau.$$

The best reply function of the domestic country is increasing: for a fixed emission tax the optimal price increases as the foreign price is increased. Moreover, in a stable market equilibrium, an increase in the tax rate will cause a downward shift in the domestic reply function and hence decrease the equilibrium prices. So, an increase in taxes, starting from taxes equal to marginal damage, will increase social welfare. Henceforth the optimal taxation is larger than marginal damage. So, the usual outcome that Cournot competition and Bertrand competition lead to different policy conclusions is reached here as well.

We end this section with an illustration. With linear demand and a Cobb–Douglas technology, profit maximization entails:

$$1 - 2ap + ap^f = a\left(\frac{\tau}{1-\beta}\right)^{1-\beta}\left(\frac{r}{\beta}\right)^{\beta}.$$

The domestic reaction function is upward sloping in the price charged by the foreign competitor. Moreover, an increase of the emission tax will cause a downward shift of the reaction curve. Hence, given the foreign reaction curve, it is optimal to set an emission tax higher than marginal damage.

5 OLIGOPOLY; GENERAL EQUILIBRIUM

5.1 Introduction

The previous section addressed the question whether governments have an incentive to deviate from the Pigouvian environmental tax rule in the case of an oligopoly, in the context of a partial equilibrium model. In the absence of a home market and with a single supplier per country the answer is in the affirmative. Moreover, in these circumstances the emissions tax is too low in the case of Cournot competition on the world market, whereas the reverse holds for Bertrand competition. If there are multiple domestic firms these results do not generally hold anymore. Kennedy provides an example where the tax is still below the Pigouvian one in a coordinated optimum and even lower in the Nash game played between the two governments.

In the present section, we revisit the question posed in a general equilibrium setting, keeping as much as possible the spirit of the models studied above. As before we abstract from domestic consumption of the exported commodity. There is a single competitor on the world market. And we do not allow for abatement. The main modification is that the economy now has two sectors, both using a polluting input as well as capital, assumed mobile across sectors, but immobile between countries. The motivation for analyzing oligopoly in a general equilibrium setting is that the strategy of increasing domestic production by relaxing emission standards has an effect on the allocation of capital in the economy through the rate of return. In particular, by making the polluting input less expensive also the sheltered sector might be stimulated. This effect is neglected in a partial equilibrium setting. It will be shown below that the effect can be important and may imply policy recommendations opposite to the ones obtained for the partial equilibrium discussed in the previous section. In the next subsection 5.2 we consider Cournot competition, Bertrand is dealt with in subsection 5.3. Finally, in 5.4 we consider the case of an emission ceiling.

5.2 General Equilibrium: Cournot Competition

The aim of this section is first to derive and characterize the social optimum for the home economy if the supply by the foreign firm is taken as given. It is shown that a uniform emission tax cannot implement this allocation. The underlying idea is simple. In the economy there are two distortions: one is the environmental distortion and the second is the fact that the world market is non-competitive. The latter distortion is fully exploited if there were a single domestic firm acting as an oligopolist on the world market. Here the absence of a domestic market is crucial of course. The former distortion can be solved independently, using uniform emission taxes equal to marginal damage. If there are multiple domestic firms the latter distortion is not fully internalized. The formal proof of this is quite similar to the exercises performed before. It is given for the sake of completeness. The first-best optimum is the solution of maximizing social welfare

$$W = U(c_1, c_3) - D\left(z_1 + \sum_{i=1}^{n} z_2^i\right)$$

subject to

$$c_1 = F_1(k_1, z_1), \tag{39}$$

$$c_3 = \sum_{i=1}^{n} p_2(x_2, x_2^f)x_2^i = \sum_{i=1}^{n} p_2\left(\sum_{j=1}^{n} x_2^j + x_2^f\right)x_2^i, \tag{40}$$

$$x_2^i = F_2^i(k_2^i, z_2^i), \quad i = 1, 2, \ldots, n, \tag{41}$$

$$k_1 + \sum_{i=1}^{n} k_2^i = k. \tag{42}$$

So, the exposed sector only exports. The export revenues are used for the import of a third commodity. The world market price of the exported commodity is p_2 and depends on supply from the home country $x_2 = (x_2^1, x_2^2, \ldots, x_2^n)$ and foreign supply x_2^f. The Lagrangian reads

$$L = U(c_1, c_3) - D\left(z_1 + \sum_{i=1}^{n} z_2^i\right) + \mu_1[F_1(k_1, z_1) - c_1] + \sum_{i=1}^{n} \mu_2^i[F_2^i(k_2^i, z_2^i) - x_2^i]$$
$$+ \mu_3\left[\sum_{i=1}^{n} p_2\left(\sum_{j=1}^{n} x_2^j + x_2^f\right)x_2^i - c_3\right] + \bar{r}\left[k - k_1 - \sum_{i=1}^{n} k_2^i\right].$$

The necessary conditions are

$$\frac{\partial U}{\partial c_1} = \mu_1, \quad \frac{\partial U}{\partial c_3} = \mu_3, \tag{43}$$

$$\mu_1\frac{\partial F_1}{\partial k_1} = \bar{r}; \quad \mu_1\frac{\partial F_1}{\partial z_1} = D', \tag{44}$$

$$\mu_2^i \frac{\partial F_2^i}{\partial k_2^i} = \bar{r}; \quad \mu_2^i \frac{\partial F_2^i}{\partial z_2^i} = D', \quad i = 1, 2, \ldots, n, \tag{45}$$

$$\mu_3 \left[p_2' \sum_{i=1}^{n} x_2^i + p_2 \right] = \mu_2^i, \quad i = 1, 2, \ldots, n. \tag{46}$$

The multipliers μ_1, μ_3 and $\bar{r}$ correspond to the two consumer commodities and capital, respectively.

Suppose that the emission tax rate is uniformly set equal to marginal damage: $\tau = D'/\mu_3$. Define $p_1 = \mu_1/\mu_3, \quad p_3 = 1, \quad r = \bar{r}/\mu_3$. It follows from utility maximization that $\partial U/\partial c_1 = p_1 \partial U \partial c_3$. Profit maximization on the part of exporting firm i implies $\{x_2^i p_2' + p_2\} \frac{\partial F_2^i}{\partial k_2^i} = r$, $\{x_2^i p_2' + p_2\} \frac{\partial F_2^i}{\partial z_2^i} = \tau$. Starting from undifferentiated emission taxes we then have

$$\begin{aligned} dW = \frac{\partial U}{\partial c_3} p_2' \Bigg[& \left(\sum_{i=1}^{n} x_2^i - x_2^1 \right) dx_2^1 + \left(\sum_{i=1}^{n} x_2^i - x_2^2 \right) dx_2^2 \\ & + \cdots + \left(\sum_{i=1}^{n} x_2^i - x_2^n \right) dx_2^n + \left(\sum_{i=1}^{n} x_2^i \right) dx_2^f \Bigg]. \end{aligned}$$

With identical domestic producers, each supplying $\tilde{x}_2$ the expression for the marginal change in welfare boils down to

$$dW = \frac{\partial U}{\partial c_3} p_2' n \tilde{x}_2 [(n-1) d\tilde{x}_2 + dx_2^f].$$

Therefore, even in this case a uniform tax rate is not sufficient to implement the optimum. An increase in the tax rate, still taking x_2^f fixed will increase social welfare because it decreases domestic supply on the world market. So, we consider the case of a single domestic supplier from here on.

Obviously the impact of a deviation of a tax rate from the initial state is zero if the policy maker takes foreign supply as given. The more interesting case arises if the domestic firm can be made to supply as a Stackelberg leader. This is achieved through the government's tax policy. In order to perform the analysis we assume that the home country is the Stackelberg leader and the other country is the follower. In the game, there are essentially four players, the two oligopolistic firms and the two governments. The individual firms are Nash players on the world product market. In the Cournot setting they take their rival's supply as given. One way to model the game at the level of the governments is to assume that the foreign government, the follower, takes the tax rates set by the home government as given, and maximizes its own welfare given these taxes. However, this complicates matters for the following reason. The tax structure in the home country does not completely determine the home country's supply on the world market, because supply is also affected by the supply of the foreign firm, which is subject to taxation in the foreign country. Therefore, with this setup the foreign country can still have a considerable indirect effect. In addition large difficulties turn out to arise if one then wants to actually calculate the Stackelberg equilibrium. In order to overcome this complication, we assume that the foreign government only observes world market supply by the home firm (x_2), takes this as given, and subsequently determines its own optimal tax structure. As a result, for any given x_2 the foreign government sets uniform emissions taxes that maximize social welfare. These taxes then also generate foreign supply. Subsequently, the home government takes the overall reaction function of the foreign country into account in determining its own optimal taxes.

The first step to be taken then is to derive the other country's reaction function and to incorporate it into the objective function of the leader. Since it is the main purpose of this exercise to show that the general equilibrium result may essentially differ from the result obtained for the partial equilibrium model we restrict ourselves to an example. It is assumed that the countries are identical, in terms of technologies and preferences. They may differ with respect to capital endowment. We employ the specifications of Section 3 with an isoelastic world demand function. National income equals $p_1F_1 + p_2F_2$. In view of the utility functions and in the absence of domestic consumption of the exported commodity, it follows from utility maximization on the part of the consumers that: $p_1c_1 = \frac{1}{2}[p_1F_1 + p_2F_2]$ and $p_1c_1 = \frac{1}{2}[p_1F_1 + p_2F_2]$. Equilibrium on the current account implies $c_3 = p_2F_2 = p_2x_2$. Hence $p_1c_1 = p_2F_2 = p_2x_2$. Profit maximization in the sheltered sector requires that the equilibrium prices are on the factor price frontier. Profit maximization on the part of the exporting sector implies

$$(x_2 + x_2^f)^{1/\varepsilon}\left[1 + \frac{x_2}{\varepsilon[x_2 + x_2^f]}\right] = \left(\frac{r}{\beta}\right)^{\beta}\left(\frac{\tau_2}{1-\beta}\right)^{1-\beta} = f_2(r, \tau_2).$$

The capital and raw material inputs are given by (20)–(23). The mathematical problem faced by the government can be stated as the maximization of

$$\ln p_2(x_2 + x_2^f)x_2/p_1 + \ln p_2(x_2 + x_2^f)x - \frac{1}{2}[z_1 + z_2]^2$$

subject to the conditions mentioned above. Also the foreign country solves this problem, thereby taking home country's supply as given. Therefore, it will not apply differential emission taxation. Welfare optimization of the foreign country then yields its world market supply as a function of supply by the home country. Unfortunately, the foreign country's problem cannot be solved in such a way that the sensitivity with respect to home supply can be determined analytically, as one would wish to do in order to find out how to set optimal taxes in different circumstances. For that reason, we report on a number of numerical calculations made in Elbers and Withagen (2002a and 2003). In subsection 5.4, where we deal with a general equilibrium with an oligopoly and exogenous emission constraint, we will be able to say more about this in an analytical way.

In the calculations we discuss here, the capital endowment of the home country is 10, for the foreign country it is 5. The price elasticity of world demand is –2. The production elasticity of capital in the sheltered sector is 0.965 for both countries and 0.8 in the export sector, corresponding with energy shares of 3.5% and 20%, respectively, as is the case in the Netherlands. With these numerical values it is found that the domestic tax rates in the Stackelberg equilibrium equal 0.49 and 0.50 in the sheltered and the exposed sector, respectively. Subsequently numerous sensitivity analyses were performed, with regard to price elasticity, production elasticity and capital endowment, all suggesting that a more strict treatment of the exporting sector is in order. The intuition behind this result is that if the sheltered sector would be treated in a more lenient way, it would demand more capital, at the expense of the sheltered sector. This additional demand and production would not sufficiently be compensated by more exports, at the expense of the foreign country.

5.3 General Equilibrium: Bertrand Competition

In this section, we analyze general equilibrium with price competition. The social optimum is the solution of the following optimization problem: maximize

$$W = U(c_1, c_3) - D\left(z_1 + \sum_{i=1}^{n} z_2^i\right)$$

subject to (39), (40), (42) and

$$c_3 = \sum_{i=1}^{n} p_2^i x_2^i(p_2, p^f) \tag{47}$$

with $p_2 = (p_2^1, p_2^2, \ldots, p_2^n)$. Necessary conditions for a social optimum are (43)–(46) and

$$\mu_3 x_2^i(p_2^i, p_2^f) + \sum_{j=1}^{n} (\mu_3 p_2^j - \mu_2^j) \frac{\partial x_2^j(p_2, p_2^f)}{\partial p_2^i} = 0, \quad i = 1, 2, \ldots, n. \tag{48}$$

Suppose that the emission tax rate is uniformly set equal to marginal damage: $\tau = D'/\mu_3$. Define $p_1 = \mu_1/\mu_3$, $p_3 = 1$, $r = \bar{r}/\mu_3$. It follows from utility maximization that $\partial U/\partial c_1 = p_1 \partial U/\partial c_3$. Profit maximization on the part of exporting firm i implies $\{x_2^i + p_2^i \frac{\partial x_2^i}{\partial p_2^i}\} \frac{\partial F_2^i}{\partial k_2^i} = r \frac{\partial x_2^i}{\partial p_2^i}$, $\{x_2^i + p_2^i \frac{\partial x_2^i}{\partial p_2^i}\} \frac{\partial F_2^i}{\partial z_2^i} = \tau \frac{\partial x_2^i}{\partial p_2^i}$. Starting from undifferentiated emission taxes we then have, after straightforward but tedious calculations

$$\begin{aligned} dW = \frac{\partial U}{\partial c_3} \Bigg[& \left\{ x_2^1 - \sum_{j=1}^{n} x_2^j \frac{\partial x_2^j/\partial p_2^1}{\partial x_2^j/\partial p_2^j} \right\} dp_2^1 + \left\{ x_2^2 - \sum_{j=1}^{n} x_2^j \frac{\partial x_2^j/\partial p_2^2}{\partial x_2^j/\partial p_2^j} \right\} dp_2^2 \\ & + \cdots + \left\{ x_2^n - \sum_{j=1}^{n} x_2^j \frac{\partial x_2^j/\partial p_2^n}{\partial x_2^j/\partial p_2^j} \right\} dp_2^n - \left\{ \sum_{j=1}^{n} x_2^j \frac{\partial x_2^j/\partial p_2^f}{\partial x_2^j/\partial p_2^j} \right\} dp_2^f \Bigg]. \end{aligned}$$

For $n = 1$ this expression boils down to

$$dW = -\frac{\partial U}{\partial c_3} x_2 \frac{\partial x_2/\partial p_2^f}{\partial x_2/\partial p_2} dp^f.$$

Therefore, if the policy maker takes the foreign price as given the impact of a deviation of a tax rate from marginal damage is zero: with only one domestic supplier it is optimal from a social welfare point of view to have all emission taxes equal to marginal damage. Hence there is no reason to discriminate against specific sectors or to favor sectors.

Again, the more interesting case is where the domestic firms can be made to act as von Stackelberg leaders. A numerical analysis with the home country as the leader and the foreign country as the follower has been performed in Elbers and Withagen (2002b). For $\alpha = 0.4$, $\beta = 0.2$, $k = k^f = 10$, $x_2(p_2, p_2^f) = 1 - 0.2p_2 + 0.4p_2^f$ it is found that with the home country as the leader it will set $\tau_1 = 3.93$, which equals marginal damage, and $\tau_2 = 1.84$. For a large set of alternative parameter values it is found that the optimal policy entails lower emission taxes for the exposed sector than for the sheltered one.

5.4 General Equilibrium With Emission Constraints

Finally, we reconsider the case of Cournot oligopoly but with an exogenous emission constraint. Recently this case was extensively studied by Mulatu *et al.* (2006). This is an interesting case with regard to the emission constraints imposed by e.g. the Kyoto protocol. The question to be addressed is whether in the case of such an emission ceiling it is advantageous from a social welfare point of view to install different permit trading systems for the different sectors of the economy or to impose different emission taxes.

The analysis is restricted to a single domestic producer ($n = 1$) of the exportable acting as a duopolist on the world market. As before, the exported commodity is not consumed domestically. With $\bar{z}$ as the upper bound on emissions the emission constraint reads

$$z_1 + z_2 = \bar{z}. \tag{49}$$

Totally differentiating the home country's welfare function, yields:

$$dU = \frac{\partial U}{\partial c_3}[\tau_1 dz_1 + \tau_2 dz_2 + x_2 p' dx_2^f].$$

Hence, if the home country takes foreign supply as given ($dx^f = 0$), then it is optimal to set equal emissions taxes or to install a uniform system of tradable emissions permits, since then $\tau_1 dz_1 + \tau_2 dz_2 = \tau[dz_1 + dz_2] = 0$.

However, matters change if by manipulating the domestic emissions tax rates foreign supply can be affected. In that case, starting from equal taxes, a policy that reduces foreign supply is beneficial. Therefore, we assume that the foreign country is a Stackelberg follower, and the home country is the Stackelberg leader. For the outcome of the game, the slope of the foreign reaction function is crucial. On the one hand, if the foreign reaction function is upward sloping, then, starting from a situation of undifferentiated emission taxes, the home government wants to decrease its own supply to the world market, for that would increase welfare. The welfare improvement can be accomplished by increasing the tax rate applied to the exposed sector. On the other hand, if the foreign reaction function is downward sloping, a decrease of the tax rate imposed on the exposed sector is in order. The issue is again closely related to the strategic trade policy literature (see Brander and Spencer 1985, and Helpman and Krugman 1985). In two papers, Collie and De Meza (1986 and 2003) address the question whether the outputs of the oligopolists are strategic complements or strategic substitutes in a partial equilibrium model, but not in the context of a general equilibrium environmental policy setting. They show that with a demand function exhibiting a constant price elasticity, the reaction functions in a Nash equilibrium are downward sloping if and only if demand is elastic. However, in our general equilibrium setting the sign may be reversed.

The foreign country takes supply by the home country as given. Therefore it imposes a uniform emissions tax. The system of general equilibrium conditions for the *foreign* country is given by the following set of equations (explicit reference to foreign is omitted, when there is no danger of confusion):

$$\frac{z_1}{k_1} = \frac{r}{\alpha}\frac{1-\alpha}{\tau}, \tag{50}$$

$$\frac{z_2}{k_2} = \frac{r}{\beta}\frac{1-\beta}{\tau}, \tag{51}$$

$$p_1 = \left(\frac{r}{\alpha}\right)^{\alpha}\left(\frac{\tau}{1-\alpha}\right)^{1-\alpha}, \tag{52}$$

$$p_2 = (x_2 + x_2^f)^{1/\varepsilon}, \tag{53}$$

$$\left(x_2 + x_2^f\right)^{1/\varepsilon}\left[1 + \frac{x_2^f}{\varepsilon[x_2 + x_2^f]}\right] = \left(\frac{r}{\beta}\right)^{\beta}\left(\frac{\tau}{1-\beta}\right)^{1-\beta}, \tag{54}$$

$$z_1 + z_2 = \bar{z}, \tag{55}$$

$$k_1 + k_2 = k, \tag{56}$$

$$p_1 k_1^{\alpha} z_1^{1-\alpha} = p_2 x_2^f, \tag{57}$$

$$x_2^f = k_2^{\beta} z_2^{1-\beta}. \tag{58}$$

Equations (50) and (51) follow from cost minimization, and Eq. (52) follows from perfect competition in the sheltered sector. Equation (53) is world demand. Equation (54) follows from profit maximization of the exposed sector. Equations (55) and (56) are evident. Equation (57) follows from utility maximization and equilibrium on the current account: $p_1 c_1 = p_1 F_1 = c_3 = p_2 x_2$. Finally, (58) is the production function of the exposed sector. The system is solved in Mulatu *et al.* (2006), who also show that the foreign reaction function is upward sloping. So, if the home country acts as a Stackelberg leader it will set $\tau_2 \geq \tau_1$. Hence, we obtain the important insight that for the class of specifications under consideration, the exposed sector needs to be taxed more heavily than the sheltered sector if the home country is a Stackelberg leader. Optimality of this policy has not been assessed for other classes than the one considered here. However, the relevance of the result is that it runs counter to what is commonly advocated in policy circles. Moreover, the exercise supports our conjecture that the earlier result for the Cournot and Bertrand model are more general than for the specific parameters employed.

In view of political economy aspects such as rent seeking and lobbying, which may prevent the feasibility of the new tax policy, Mulatu *et al.* (2006) analyze the effect of the proposed policy on the profitability of the exposed sector. The unit cost function of the exposed sector reads

$$c_2(r, \tau_2) = \left(\frac{r}{\beta}\right)^{\beta} \left(\frac{\tau_2}{1-\beta}\right)^{1-\beta}.$$

Profit maximization boils down to the maximization of

$$\Pi_2(x_2) = p(x_2 + x_2^f)x_2 - c(r, \tau_2)x_2$$

with foreign supply given. With the isoelastic demand function (53) we have

$$\Pi_2(x_2) = \frac{x_2^2}{-\varepsilon[x_2 + x_2^f]^{1-1/\varepsilon}} = \frac{x_2^{1+1/\varepsilon^{1+1/\varepsilon}}}{-\varepsilon\left[1 + \dfrac{x_2^f}{x_2}\right]^{1-1/\varepsilon}}.$$

Therefore, in comparing the Nash and the Stackelberg tax regimes, it is clear that profitability is enhanced if domestic output increases or if foreign supply decreases relative to home supply. Indeed, supply of the traded commodity by the home country may increase compared to the Nash equilibrium. Obviously, this is not the case when the two equilibria are close to each other, because the Stackelberg leader should then increase the emission tax on the exposed sector even in absolute terms. However, when the economies differ considerably, it need no longer be the case that the Nash equilibrium tax rate is between the two Stackelberg tax rates. In Mulatu *et al.* this result is illustrated by means of a set of simulation runs. As expected, when the economies are similar with regard to initial capital it is found that the Nash equilibrium tax rate is between the Stackelberg tax rates for the sheltered and exposed sectors. Moreover, the sheltered sector suffers from the new tax regime in terms of profitability. However, with an increasing difference in capital endowment the exposed sector benefits more from the higher tax rate. Although the exposed sector pays more than the sheltered sector, the tax rate is considerably less than in the Nash equilibrium. Therefore, being a Stackelberg leader is not only welfare enhancing at the country level, but it also increases profitability in the sector that is subject to the more stringent environmental policy. However, the profit differential is positive when the foreign country is relatively well endowed, both with capital and allowable emissions. In such circumstances it is rather more difficult to justify home's Stackelberg leadership, at least within the present model.

6 CONCLUSION

This paper addresses several issues regarding international trade and environmental policy. We have reviewed the theory on the pollution haven hypothesis and highlighted some recent developments in the analysis of imperfect competition and strategic policy making. The survey shows that care should be taken with the framework in which the question of policy differentials is analyzed. The outcomes obtained in a general equilibrium approach might qualitatively drastically differ from what is found in a partial equilibrium setting.

These theoretical results have important implications for the policy debates on globalization and the environment, and the issue of harmonization of environmental policies across countries. The results relieve the frequently debated tension between trade and environmental policy objectives by suggesting that fear of ecological dumping can hardly be substantiated by means of standard neoclassical theory. Obviously, in the real world, matters are more complicated than we can currently capture in theoretical microeconomic models. Specifically, the assumption of governments behaving as strict social-welfare maximizing agents aiming to design and implement environmental policies in a socially optimal fashion is open to discussion and can be modified. It is nowadays customary to think of governments as policy brokers bringing together different interest groups with conflicting stakes in policy outcomes. Strictly speaking, one could therefore maybe rule out the possibility that policies of ecological dumping can be justified on the basis of utilitarian optimality grounds. But social optimality may not necessarily be the basis for policy-making. However, it is equally implausible to expect the game of interest groups competing for policy influence to end up *by necessity* in a situation where proponents of eco-dumping will unequivocally dominate the game.

A problematic aspect of our approach concerns the information the Stackelberg leader needs to design its optimal policy. This calls for further research. Similarly, we assume that the supply of the polluting raw material is inelastic and sufficiently high. It may very well be worthwhile, although technically much more difficult, to allow for imports of this commodity at positive world market prices. Overall, our results suggest the prevalence of a strong link between the design of international environmental agreements and the design of policies with respect to the environment and trade. A closer future investigation of this link would be worthwhile, both from a theoretical as well as a policy perspective. An important outcome of the analysis is the desirability of uniform emission taxes in many circumstances. However, it should be kept in mind that this is in part due to the specific damage functions employed, where damage only depends on aggregate emissions. It would be interesting to see how this conclusion changes when this is no longer the case, for example when location matters. Finally, it would be very worthwhile to incorporate imperfect competition and strategic government behavior in the Copeland–Taylor model, in order to say more on the resulting trade patterns.

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